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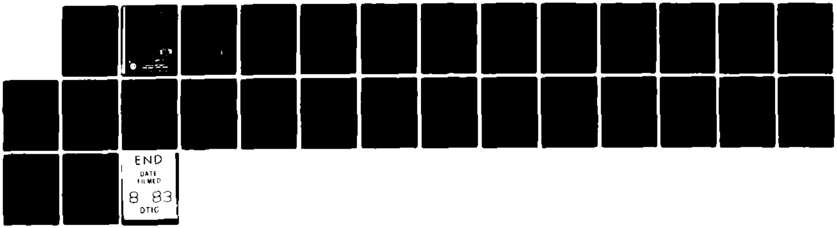

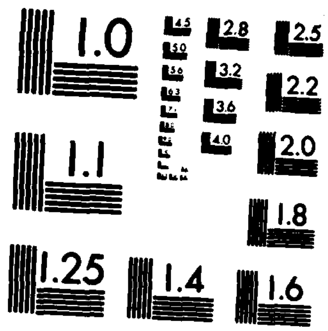

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The Korean Auroral Records of the Period
AD 1507-1747 and the SAR Arcs

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The Korean Auroral Records of the Period AD 1507-1747 and the SAR Arcs

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ABSTRACT

There are many reports of auroral sightings in Korea during the period AD 1507-1747. On the basis of all their characteristics as reduced from the descriptions of these reports and from several statistical analyses, we believe that most of them were not usual auroras, but most probably were so-called Stable Auroral Red arcs.

1. Introduction

Recently Dai Nianzu and Chen Meidong (1980) compiled a new auroral catalogue which contains 932 reports of auroral sightings in China, Korea and Japan from the time of legends to AD 1747 (Dai Nianzu et al., 1980). One of the catalogue's remarkable characteristics is that the rate of Korean sightings increased rapidly since the 16th century AD. For the period from AD 1507 to 1747 there are 435 items altogether, almost a half of the total number in the catalogue. Such an unusual situation and especially the fact that this period is an important and controversial one in the search of the past behavior of the sun (the Maunder Minimum, AD 1640-1715, is just within this period) compels us to doubt their reality. How to treat and handle these Korean records will directly affect our understanding of solar activity during this period. Therefore, before we use them, it is necessary to examine their reliability carefully, and judge what they were. Below we will do this in several ways.

2. Judgement from the difference of descriptions of records

There are some apparent differences between the descriptions of Korean auroral reports before and after about AD 1500. Most of the records before this time have relatively detailed descriptions. Besides the observing time, place, direction and position in the sky, the reports

also give some other very useful and crucial information which can be used to identify them. Examples are the color, brightness, shape, size or extension in the sky, duration of the display, and even the movement and change of these features with time. For example, the report of December 23 of AD 1141 says "..., at night, a red vapor appeared on the north sky, then two other strips of white vapor penetrating through the north pole and vicinity appeared also, sometimes they disappeared and then reappeared again;" the report of March 19 of 1176, "...at night, a red vapor appeared in the west sky, it looked like a shield and was about 15 chi* long;" and the one of October 25 of 1279, "...,a purple vapor could be seen in the West sky, more than 10 chang* long, as bright as a bolt of lightening." Generally speaking, with such a detailed description we can judge them to be auroras without any doubt.

After that time, however, the overwhelming majority of Korean records (more than 85%) only give a very simple description. A typical description, usually, consists of only 3 or 4 Chinese words besides the words describing the time, place and direction, i.e., "On May 5 of 1554, at night it seemed to have been a fire-like vapor in the south sky" or "..., there was a vapor resembling fire" or "..., there

*Both are chinese length units. 3 chi = 1 meter, 1 chang = 3.3 meters.

was a vapor resembling the light of fire." Beside the color (red) we can probably get no other clear and definite features from such a simple description. It is necessary here to point out that not all of the records of the period AD 1507-1747 have such a simple description. Some descriptions are relatively detailed, just as the descriptions we cited above. Here we should emphasize the fact that both simple and detailed records are recorded in the same document. We can often see that among several simple records which are close in time there is a detailed one. In addition, there is an obvious difference between detailed and simple records, that is, for the detailed records the observed objects are commonly called "red vapor", the traditional common term for the auroras, while for the simple ones they are called "vapor" or "fire vapor". This wording difference reflects obviously the difference between observed phenomena themselves.

The observing and recording of the sky phenomena were carried out by the same specialists, who passed from generation to generation, in the observatories established and controlled by Korean emperors and government. Considering this, the most natural and reasonable explanation for these differences in the descriptions is that how detailed and precise a record is just reflects how clear the observed object was, rather than, for example, that different

observers and recorders had different understanding for the same phenomenon and different ways to record it. Thus, the records with simple descriptions, generally speaking, should correspond to unremarkable phenomenon without astonishing brightness, clear borders and fantastic shapes. They were most probably just some kinds of feeble glows. This inference is confirmed by the result mentioned below.

Figure 1a shows the distribution of Korean sightings with simple descriptions versus the phase of the moon. As a comparison, the distribution of Chinese and Japanese sightings, of which overwhelming majority are certainly common auroras, for the same period is also given in Figure 1b. It is apparent that the Korean sightings were strongly modulated by the moonlight, while the effect of the moonlight on the Chinese and Japanese ones is relatively much smaller.

3. Judgement by the long-term distribution

The number of historical reports of auroral sightings depends on many natural and social factors. They are mainly the level of solar activity, and thus the frequency of auroral appearances; the geographical location; the climate and weather; the social, political, and civilization conditions; and especially, ancient people's understanding of auroras and whether any special attention and effort were paid to observe them. In ancient time China (mainly

northern China) and Korea were very similar to each other in all of these respects, particularly in that the observing and recording of the auroras in both of these two countries were carried out by the so-called astronomical officials. Therefore, we assess that the difference between the numbers of reports of auroral sightings in these two countries should not be too great. In fact Figure 2a shows that the two curves for the 11th-15th centuries AD that not only is the difference between these two numbers, the frequency per century, relatively small, but also their variations with time are similar--the two curves are roughly parallel. Since the 16th century, however, the Korean curve unexpectedly rises upward to so high a value that we have to use another bigger scale to draw it. The Korean number, 299, is 23 times the Chinese! For sightings of common auroras, we can hardly imagine and accept such a rise. It is interesting here to point out that if we reject the sightings with simple descriptions, i.e., only use the ones with detailed descriptions to draw the Korean curve, the original rough parallel relation will persist, as the dashed line shows. This result leads to the same conclusion that most of the sightings in Korea during the period AD 1507 to 1747 were not common auroras.

It is worthwhile to point out that the approximate parallel relation between two curves, which we hardly think

just to be a coincidence, may suggest that most of the major auroral displays in these two countries since the 11th century AD have been observed, recorded and preserved. Furthermore, because of the well known fact that the frequency of auroral occurrences in middle and lower latitude areas is well correlated with solar activity, we can believe that the curves of Figure 2a should reflect the secular variation of solar activity. This can be confirmed by the carbon-14 concentration from the tree-ring analyses for the same period. It is clear that the auroral curves are similar to the C^{14} curve (Eddy, 1976a) in Figure 2b. This result proves once more that, as has been proved by some previous work (Yunnan Obs., 1976; Ding Youji et al., 1978; Lo Baoyong et al., 1978; Xu Zhentao et al., 1979), the Oriental historical data of sky phenomena, generally speaking, are of considerably high reliability, and can provide us with much worthy information about the behavior of the sun in past time. Here we should point out the fact that oriental records of many kinds of sky phenomena, including sunspots and auroras, were generally obtained from regular observations rather than from accidental observations and casual mention as some authors thought (Bray, 1974; Eddy, 1977).

4. Judgement from the directional distribution

It is common knowledge that the polar lights or auroras

mainly appear in the northern sky in the northern hemisphere. This can be used as one of the referential statistical criteria to judge if a group of historical records are auroras.

Figure 3 shows the directional distributions of 6 different groups of the records of sightings in the catalogue of Dai and Chen (1980), i.e., (a), (b) and (c)-- the sightings, respectively, in China, Japan and Korea for the period AD 1000 to 1499; and (d), (e) and (f)-- the same in the three countries but for the period AD 1500-1747. It is apparent that only the Korean sightings after AD 1500 shows an abnormal distribution-- most of them were seen in the south and south-east! Defining an index

$$R = \frac{N_{NE} + 2N_N + N_{NW}}{N_{SE} + 2N_S + N_{SW}},$$

where N_N, N_{SE} ,..., are respectively the numbers of records which were seen in the north, south-east, ..., we get

$$R(a) = 5.05 \quad , \quad R(d) = 5.75,$$
$$R(b) = 6.33 \quad , \quad R(e) = 7.00,$$
$$R(c) = 1.84 \quad , \quad R(f) = 0.39.$$

The R values corresponding to Chinese and Japanese

records all exceed 5 meaning that they are of high reliability in view of the direction distribution. The value corresponding to Korean records of AD 1500 to 1747 is very small, only 0.39. It is hard for us to accept such a curious result that during the same period the direction distribution of auroral sightings in Korea is statistically opposite to those in China and Japan, which are located very close to Korea. It seems that the most reasonable explanation for this curious result is still our inference above, i.e., most of Korean sightings of this period are not common auroras.

5. Why were there so many sightings in Korea during the period AD 1507 to 1747?

In ancient Korea it was believed that the aurora was a kind of mysterious and divine light, and that it was closely related to terrestrial natural events and social incidents. Auroras were, in other words, precursors of these events and incidents. So the emperors and governments paid close attention to their observations. During the 16th and 17th centuries this situation seemed to be especially serious. We can find more cases from historical documents that the astronomical officials who were in charge of the observations of auroras were condemned for dereliction of duty, i.e., failing to observe and report the appearances of

auroras, than before. Thus, it seems to be reasonable to partially attribute the cause to the pressure on the astronomical officials. Because of this the observers not only watched the night sky very carefully but also reported any possible "aurora", even though it was very faint. In other words, they reduced the recording and reporting standards. Thus, a lot of reports were engendered. Was there any lie among these reports? We think such a possibility must be very small. The reason is simply that lying itself was also guilt. This means that the Korean observers did see <u>somethings</u> in the night sky. Because the things they saw could not be seen clearly, they had to record them with simple and somewhat ambiguous descriptions.

6. What were they?

From the discussion above we have already obtained some of their characteristics, that is, they were some feeble glows with reddish color, without clear borders and complex shapes, and mainly seen in south-east and south sky. In order to seek for their other characteristics we examined their time distribution as a function of months, and carried out an autocorrelation analysis through them. The results are shown in Figure 4 and Figure 5 respectively. Figure 4 shows that they preferred to occur near the vernal equinox. From Figure 5 we can get an important property. It can be

seen that peaks occur near lags of 10, 20, 30, ..., years, except that the peak near 50 years is pressed so low by the long-term variation that it can not be seen clearly. We attribute this result to the modulation of their occurrences by the 11-year cycle of solar activity.

On the basis of all the characteristics we can infer that the simple reports most probably described so-called Stable Auroral Red Arc (SAR arcs) or Mid-latitude Red Arc or M-arc (Hoch, 1973; Roach et al., 1963; Rees, et al., 1975). SAR arcs generally occur in mid-latitudes and have an east-west extension of thousands of kilometers and even possibly extend around the Earth. SAR arcs are generally stable, homogeneous, and several hundred kilometers wide in the meridional direction. They extend from 300 to 700 km in height. They are due to the excitation of atomic oxygen by hot electrons in the plasmapause region, and are almost monochromatic in red lines 6300 Å and 6364 Å, the doublet of atomic oxygen. Their intensity is positively correlated with geomagnetic activity, and their occurrences are positively correlated with sunspot activity. They occur most frequently near the equinoxes. The characteristics of our unknown phenomenon are rather consistent with these of SAR arc.

It should be pointed out that the fact that SAR arc is

a kind of subvisual phenomenon does not mean that our inference is wrong and impossible. In terms of theory, if the level of solar activity is high enough to enhance the mean intensity to approach or exceed a certain value, for example, 10 KR (kilo-Rayleigh), the visibility threshold, 10 KR (Kilo-Rayleigh), some SAR arcs with extremely high intensity may appear in the moonless night sky as visible luminous objects. In such a time, if we scout the sky carefully, we may have some opportunities to see them with the naked eyes. During the last about 200 years perhaps some visible SAR arcs appeared at times, but people did not pay attention to them, since they were too faint, similarly the nightglows did not receive attention until the present century (Rayleigh, 1931).

If our inference above are true, we can deduce that during the periods of AD 1500-1570 and AD 1610-1640 the general levels of solar activity were likely higher than or at least not lower than that during recent decades.

As for the Maunder Minimum, AD 1640-1715, we can see that the solar activity was relatively lower. But in view of the fact that there were some sightings reported indeed, rather than nothing, we can confirm again our previous conclusion (Ding Youji et al., 1978) that the level of solar activity during the Maunder Minimum was not so low as Eddy

claimed (1976b).

It is also necessary to point out: 1) We can not rule out the possibility that some of these Korean sightings were nightglows or zodiacal lights, but judging by the color and direction distribution, the possibility is very small; 2) Although SAR arc may be classified as aurora, it differs from common aurora with respect to the intensity, the mean height, the latitude distribution, etc. Therefore, we should differentiate the SAR arcs from the common auroras when we collect, arrange, and investigate the data with respect to the history of the solar activity, or we may get wrong results, as the result given by the uncorrected Korean curve in Figure 2; 3) The abnormal distribution of Figure 3(f) can be explained by the following discussion. Because of the motion of the geomagnetic dipole field, Figure 7, the geomagnetic latitude of Korea around the 16th and 17th centuries was higher than at present (Kawai et al., 1967). Thus in the Figure 8 the northern SAR arc zone of Roach (1963), within which the SAR arcs were observed, should during the 16th and 17th centuries be replaced by the zone labeled M'. This would give more opportunity for observing SAR arcs in Korea during this period. The SAR arcs displayed in Korea should generally have swept up the sky from south-east to north-west, as shown in Figure 9. Since the SAR arcs were very faint themselves, a small difference

of observing conditions, for example, the transparencies of the atmosphere, in different directions could affect the directional distribution of SAR arc sightings. If the observing conditions in the southern sky were generally better than that in the northern sky during this period at the observing places, mainly Kaesong and Seoul, the surprising distribution could be produced. This may also be used to explain why the R value of Korean records of AD 1000 to 1499 is relatively small.

7. Conclusion

We believe that most of the Korean sightings of the period AD 1507-1747 were not usual auroras, but most probably were SAR arcs. If our inference is true, these Korean records will provide a new kind of useful historical data for the investigation of the history of the geomagnetic activity and of the solar activity. Maybe one day in the future when solar activity rises high enough, the SAR arcs will "often" appear in the night sky with their soft reddish color.

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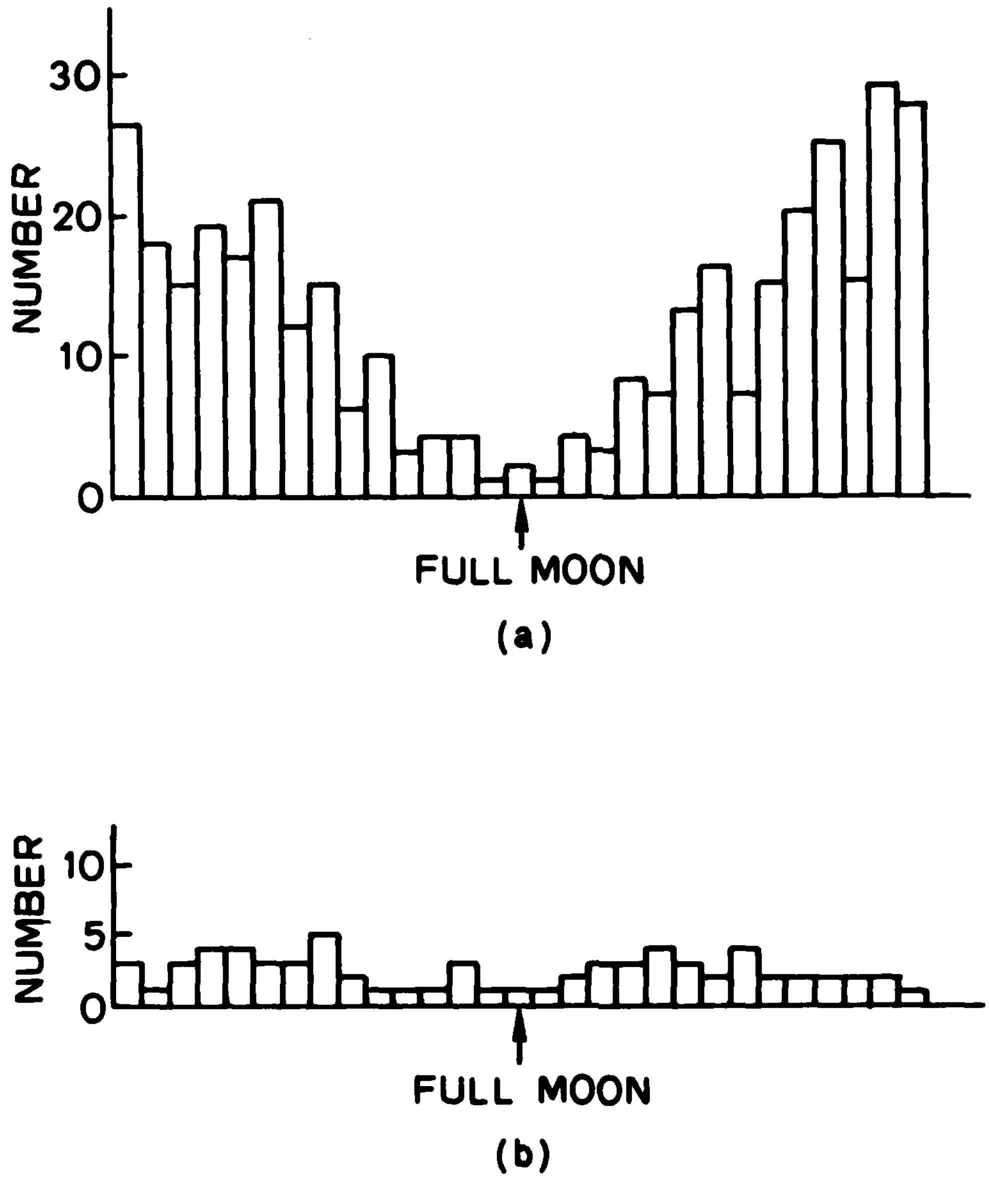

Fig. 1(a) The time distribution of Korean sightings with simple descriptions as a function of lunar calendar for the period AD 1500-1747; (b) The same, but for the Chinese and Japanese sightings.

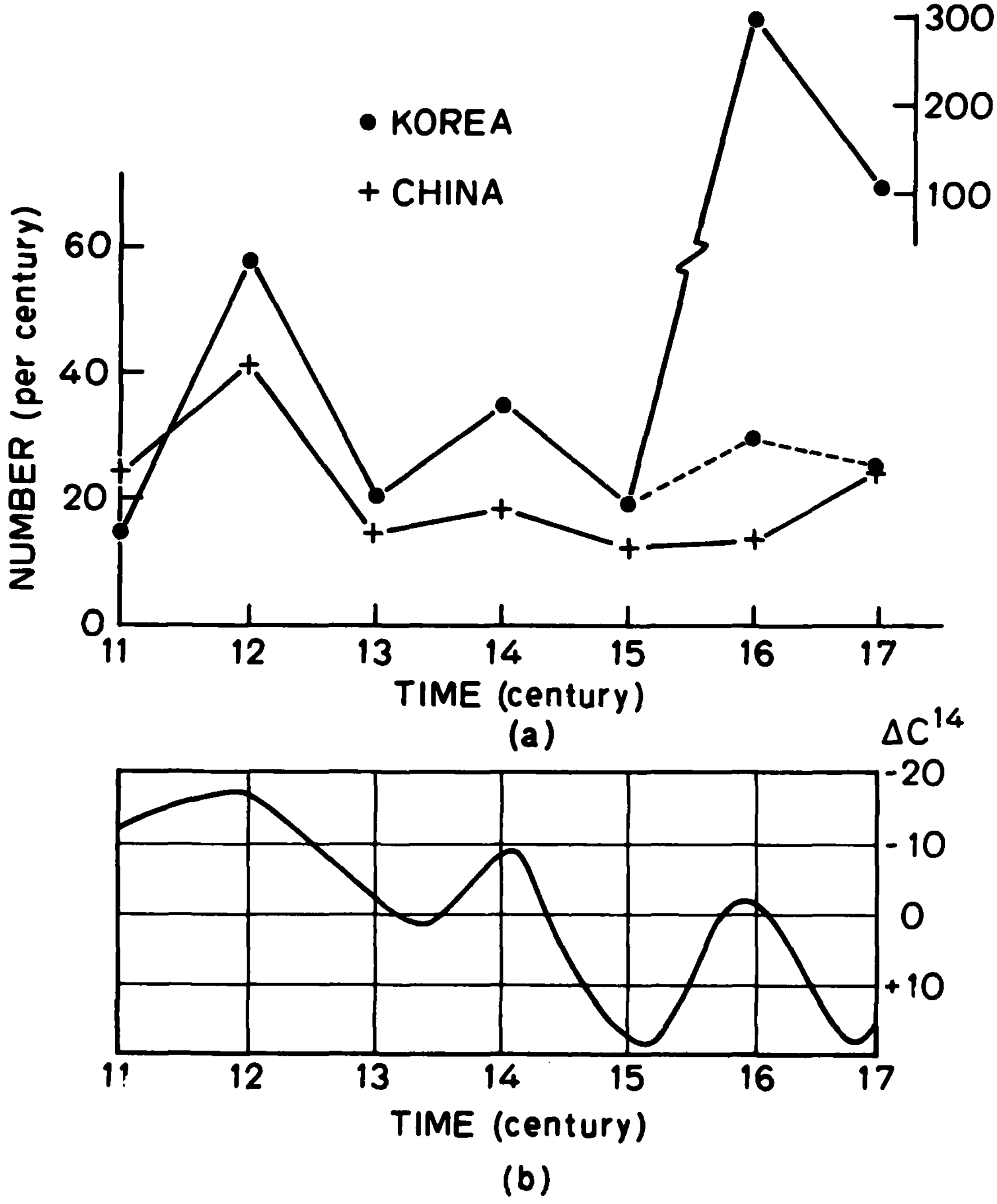

Fig. 2(a) Auroral sighting records from China and Korea from 11-17th centuries. (b) Carbon-14 concentration from tree-ring analysis (from Eddy 1976).

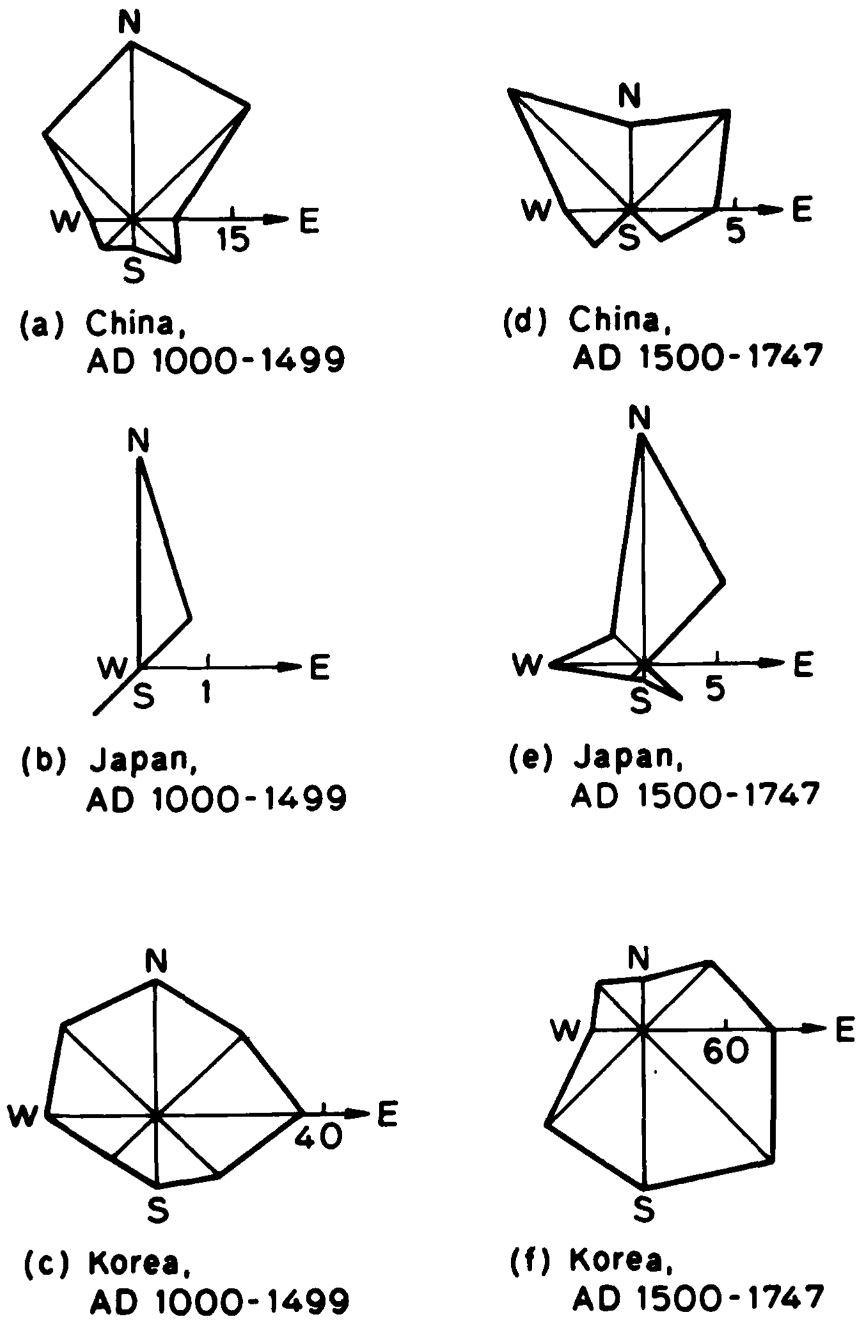

Fig. 3 Directional distribution of six groups of auroral sightings.

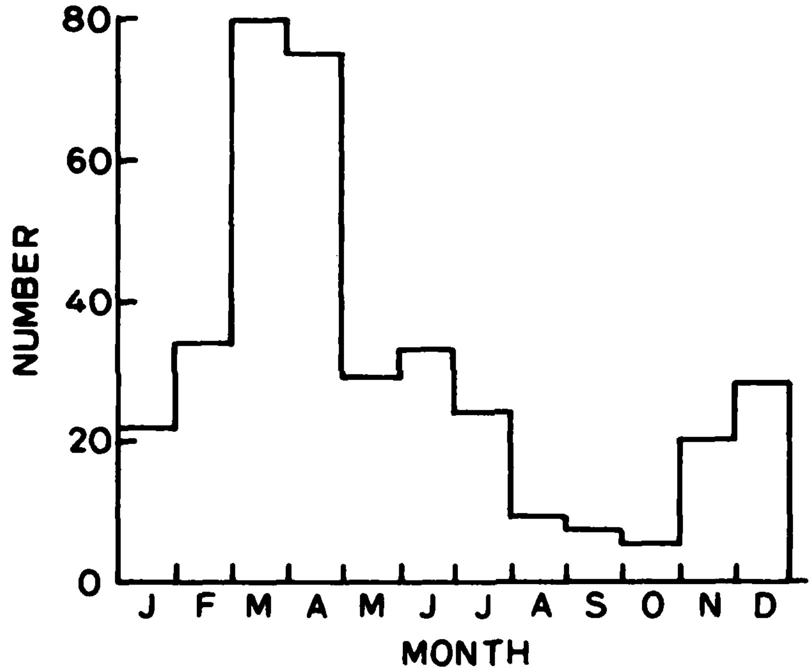

Fig. 4 Monthly distribution of Korean records with simple descriptions.

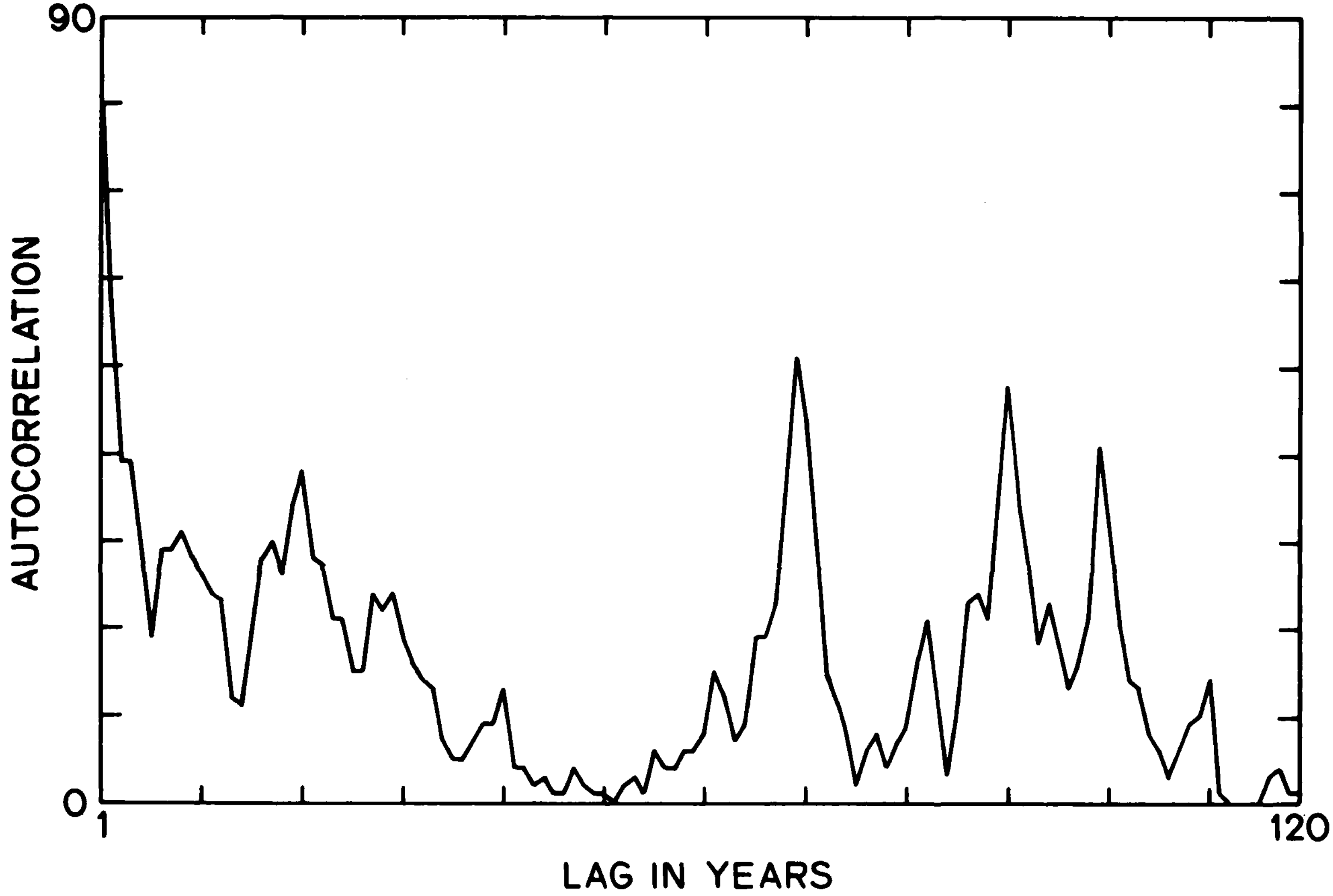

Fig. 5 Autocorrelation function of Korean records with simple descriptions.

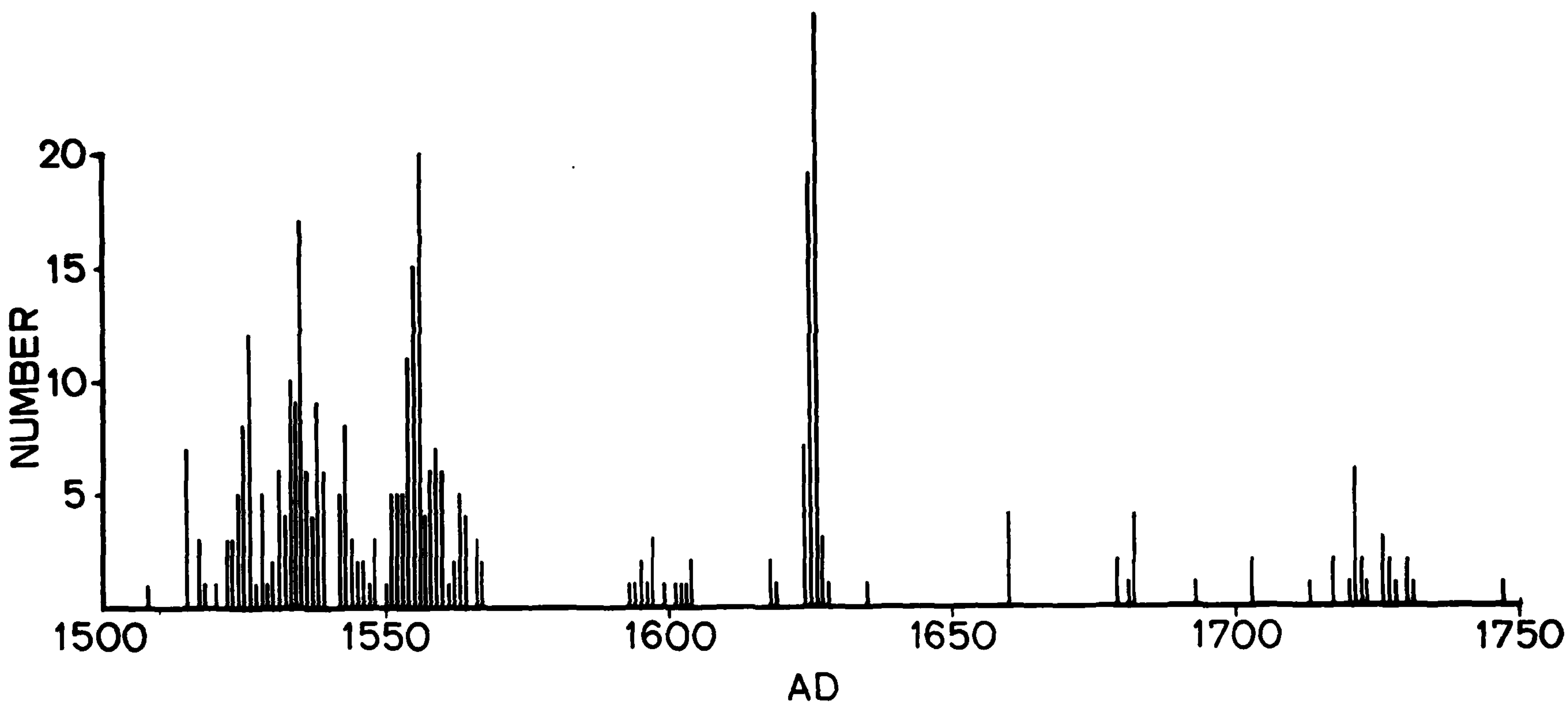

Fig. 6 Distribution of Korean records with simple descriptions for the period AD 1500 - 1750.

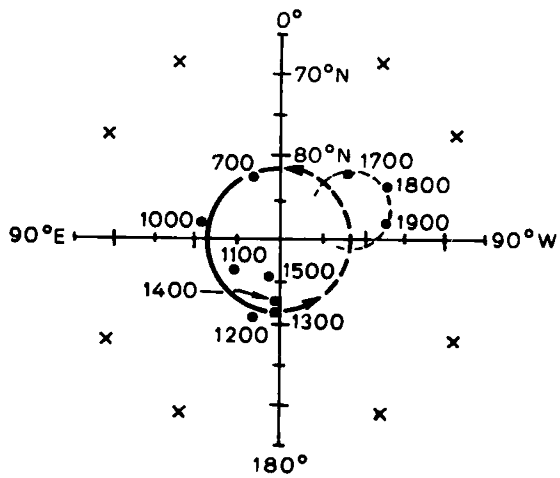

Fig. 7 Anticlockwise motion of the geomagnetic dipole axis is shown by a thick circle.

Recent secular field inferred from various geomagnetic observatories; such as Ascension Island, Boston, Cape Town, Hongkong, London, Rio de Janeiro, Sicily etc., is shown by a broken circle. (Kawai, Hirooka and Sasajima, 1965).

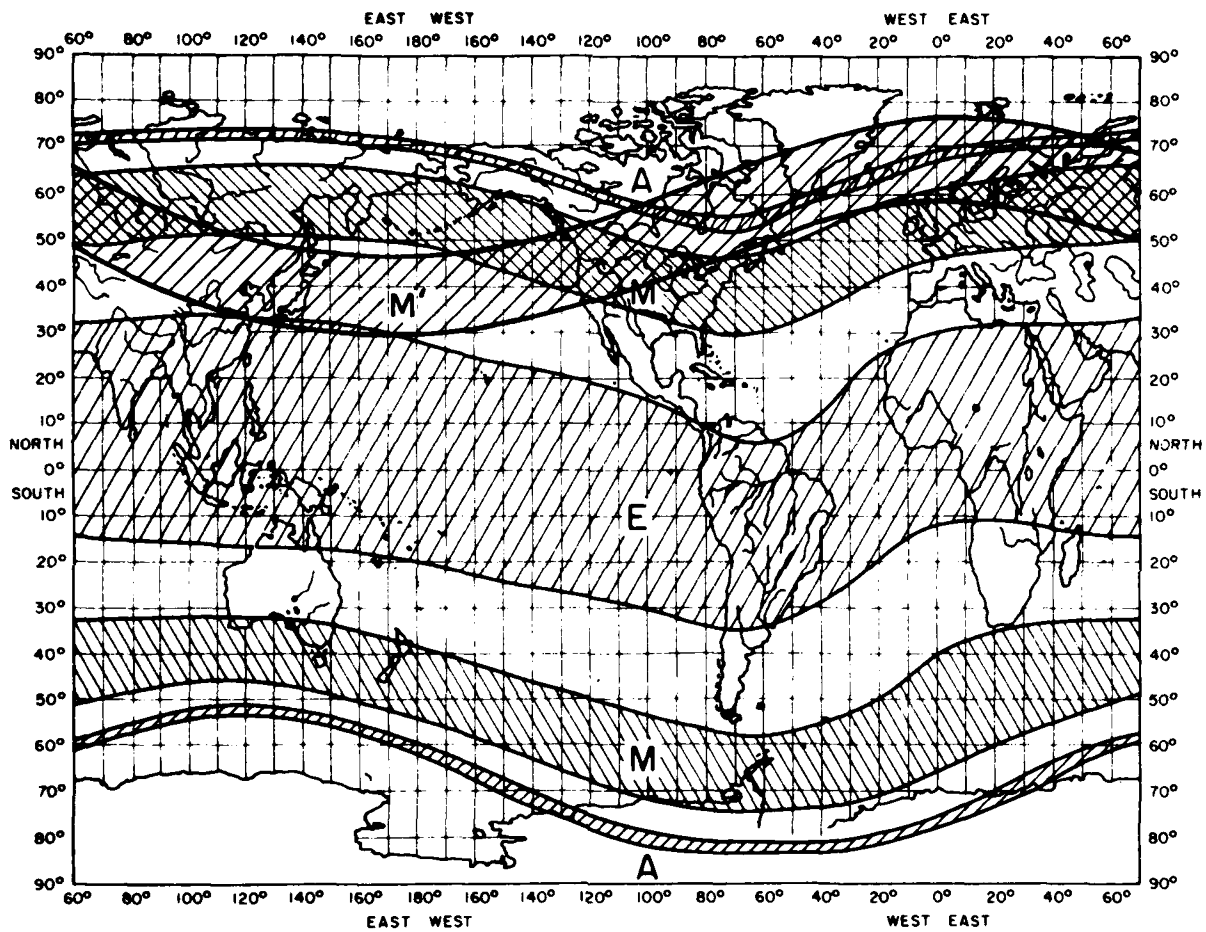

Fig. 8 Zones of $\lambda 6300$ emission enhancements: E, equatorial arcs; M, SAR arcs at present time; M', SAR arcs around the 16th - 17th centuries; A, Aurora.

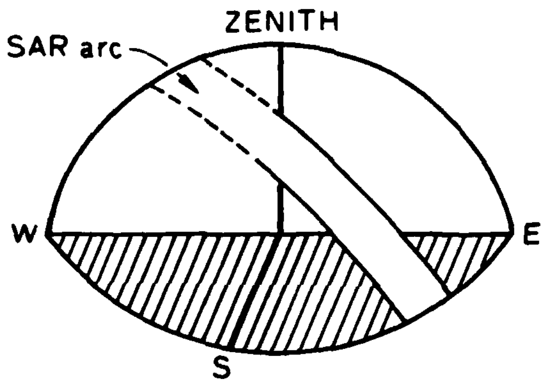

Fig. 9 Illustration of the directional distribution of Korean records with simple descriptions of the arcs (SAR arcs). The orientation of SAR arcs is generally from SE to NW. Since the SAR arcs are very faint, if the observing conditions are better in the SE than in the NW, then the NW part of an SAR arc (drawn in dashed line) might not be seen. Thus a distribution with SE dominance will be produced.